Greener Journal of Agricultural Sciences
ISSN: 2276-7770; ICV: 6.15
Vol. 2(6), pp. 279-288, October, 2012

http://gjournals.org/GJAS

Review Article

The Significant Role of Post-Harvest Management in Farm Management, Aflatoxin Mitigation and Food Security in Sub-Saharan Africa

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ARTICLE INFO

Article No.: *10021269*
DOI: *10.15580/GJAS.2012.6.10021269*

Submitted: *02/10/2012*
Accepted: *10/10/2012*
Published: *30/10/2012*

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Keywords:
Post Harvest losses; Aflatoxin; Supply Chain; Mitigation; food security; metal silo

ABSTRACT

Post-harvest losses in sub-Saharan region in Africa are estimated to be about 30% annually. This review examines the vital role which post-harvest management plays in the management of crop farms and in the mitigation of aflatoxin poisoning. The capitalization of this role offers a cheaper way of improving food production in the sub-Saharan region which is drought prone and has to a large extent, seen as food insecure. Studies have shown that proper post-harvest management, especially the use of the small scale metal silo, contributes to better quality of grains, less pesticide usage and can accelerate agribusiness, therefore directly contributing to rural development and poverty reduction. However, not much effort has being invested in reducing post-harvest food losses especially in staple cereals like maize and legumes, even after many studies have shown that it offers an essential way of increasing food availability without the need of other resources. Furthermore, post-harvest management offers a cheaper way for diet diversification, which is crucial in aflatoxin poisoning reduction. This review also presents a model by which can be used in reducing the entry of toxigenic *Aspergillus flavus* in the grain supply chain.

Introduction

Cereals, especially maize and legumes form a significant food source in the Sub-Saharan region. It is estimated that more than 75% of the local cereal production is provided by small scale farmers (FAO, 2011). For example, it is also estimated that about 90% of rural households in Kenya grow maize. However, the national maize supply by these small scale farmers annually decline due to a combination of crop failures in the predominantly short rains dependent region coupled with pre- and post-harvest plosses which range from 20-30%. FAO in their 2011 report spoke of the “Missing Food” in which they estimated that currently, 1 out of every 5 kilos of grain produced in Sub Saharan Africa is lost to pests and decay. This lost food is enough to feed 48 million people for 12 months
and is valued at around $4 Billion or ½ annual grain imports to Africa. This means that a reduction in grain losses could have an immediate and significant impact on people’s livelihoods. Furthermore, because cereals form a major part of the staple food of the sub-Saharan region, it is important that food security and safety concerns be identified so that appropriate control steps can be taken to prevent post harvest food losses and human health hazards. To date, the two major health concerns related to cereals in Africa are contamination with pesticide residues used in maize production and storage and fungal toxins that contaminate maize during pre and post-harvest periods especially the aflatoxins.

Aflatoxins are toxic metabolites produced by fungal species during their growth under favorable conditions of temperature and moisture (Klich, 2007). The major aflatoxin producing species are *Aspergillus flavus* and *Aspergillus parasiticus*. The main cereals affected are maize, sorghum, rice and wheat and other crops like groundnuts and cassava (Cotty, 1997, Kabak *et al*., 2006). The Aflatoxins produced are classified as B1, B2, G1 and G2. Aflatoxin B1 is the most toxic of the four. While these toxins do not seem to have physiological functions for the fungus, they are now recognized as potential carcinogens, teratogens, mutagens, immune-suppressants and have eostrogenic effects in humans (Amaike and Keller, 2011). This danger has not reduced in the major part of the Sub-Saharan region especially in Kenya and surprisingly it seems to be increasing. For instance, recently in 2010, one of the laboratories in Kenya tested 130 maize samples out of which only 47 samples had aflatoxin levels less than 10ppb. The highest level of aflatoxin recorded in that year was 830 ppb (FAO, 2011).

The growing of stressed plants has been linked with a higher infestation of *Aspergillus flavus* in crops. Hence, farm management strategies especially crop rotation, should be one of the priorities in Aflatoxin mitigation. Furthermore, there is a direct link between post harvest management and agribusiness, farm management (Schaafsma *et al*., 2001), diet diversification and food security which for a long time has not been comprehended by the various food production stakeholders. The complexity of the *Aspergillus flavus* life cycle and relationship with crops necessitates that an integrated systematic approach be adopted (Amaike and Keller, 2011). This review provides a possible model which can be used in Aflatoxin mitigation strategies.

The link between food diversification, farm management, food security and post harvest management

Cereals like maize are one of the major staple food crops in Sub-Saharan Africa. However, the climate and conditions of this area attract a huge number of factors that contribute to the destruction of the crops especially at the post-harvest level (Jones *et al*., 1981). Whenever crops are grown, insect pests and phytopathogenic microorganisms are attracted; hence the strategies which a county or individual farmers employ in post-harvest management will determine the farm utilization priority, grain quality in the market, food diversification, food security and general living standards of the people involved. However, due to poor post-harvest management strategies in the sub-Saharan region, there has been a repeated cycle of food production and post harvest losses which have systematically depleted the mineral quality of the farms leaving substantial food insecurity in the region. Although Africa is endowed with the highest level of plant diversities in the world, many of these have not been domesticated because the available land for such trials is always occupied by the same type of stable crops. This is due to recurrent heavy post-harvest losses of key farm products. Much of these losses are due to , poor storage facilities: for example, the use of traditional wooden cribs which harbor pests like the lesser and larger grain borers (Hell *et al*., 2000); indiscriminate use of pesticides which has increased pesticide resistance of insects; high humidity and moisture content of grains during storage (Hell *et al*., 2000); climate change which has caused the time of harvest and drying to be largely unpredictable. (Jones *et al*., 1981). However, proper post-harvest management strategies can enable farmers to store high quality grain which can fetch high prices in the global market. Moreover, the storage can enable a farmer to subsequently grow a different type of crop which can make a farmer to practice crop rotation (Schaafsma *et al*., 2001) and hence enhance diet diversification which is a key strategy in reducing Aflatoxin poisoning (Figure 1).

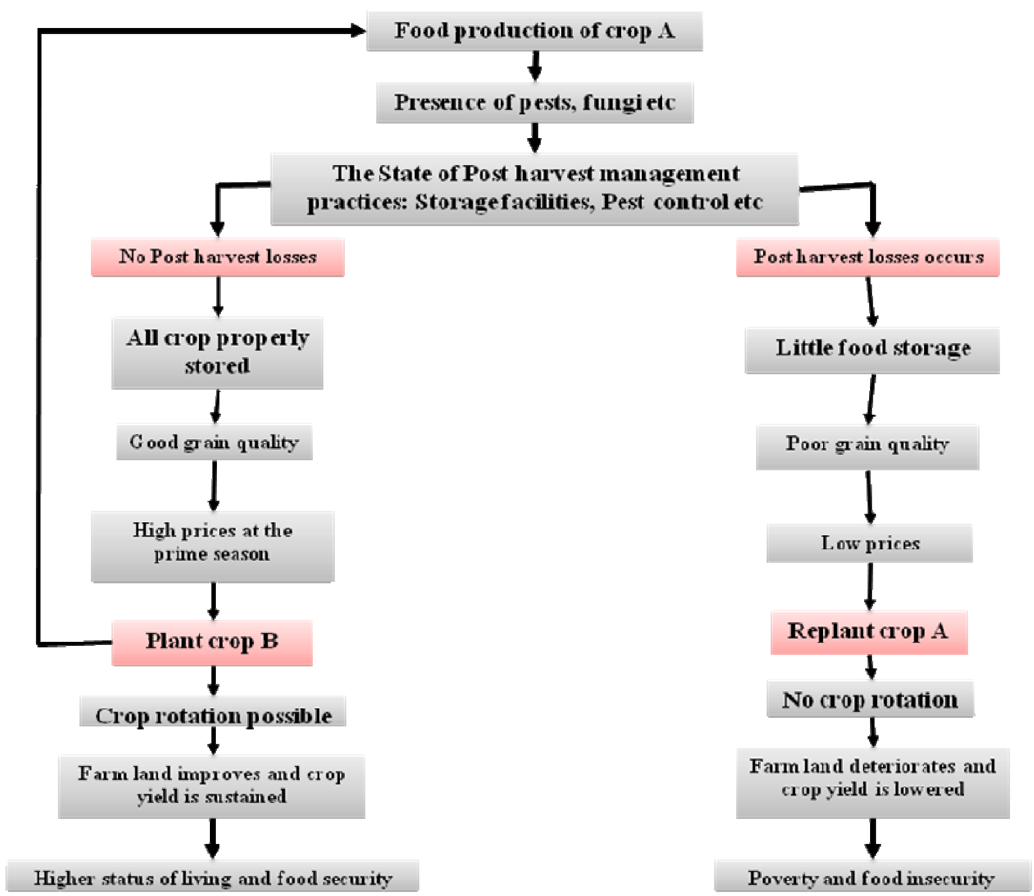

Figure 1. The relationship between food production, crop rotation, crop diversification, food security and post harvest management practices in a grain supply chain

The metal silo as a rational small scale strategy for grain storage

Weevils have been singled out as the major causes of post-harvest grain losses. These losses are mainly due to the use of traditional storage structures that are inefficient in the storage and preservation of grain (Hell *et al*., 2000). In the Sub-Saharan region, it has been established that traditional cribs and gunny bags which are the most common storage facilities, cannot guarantee protection against weevils and especially the larger grain borer that cause over 30 per cent of losses and sometimes wiping out the entire harvests during severe infestations. FAO has come up with a new technology that has helped many small scale farmer nations in Central and South America and also in Asia to keep their agricultural products safe. It has already facilitated over 16 countries to train local tinsmiths in construction of small metal silos, suitable for farming families. Over 45,000 such silos have now been made. These have enabled farmers to store their grain crops safely for long periods.

Grain weevils like the larger grain borer, hibernates in the bamboo, the reeds and the tree branches of which our traditional structures are made. So it is quite a big problem because once it is there it is very difficult to control. But the metal silo method of grain storage will starve them to death. It has many advantages; such as maintaining the quality of the stored product; it makes it possible to store grains without using pesticides which are expensive and can enter into food; it requires little space and hence economizes space; it reduces losses to virtually nil; it allows for farmers to take advantage of the fluctuating market prices of grains, since they won't sell grains just to avoid spoilage; it prevent rodents, beetles, moths and other pests that produce toxins that can harm consumer's health; it is not expensive and can last for over 30 years; it can be of various sizes; it is a tried and tested technology in many nations since it advent in 1997; it keeps the storage facilities clean and conducive for customers. The metal silo to a large extent keeps insects away which Increases the respiration rate of seeds, Increases temperature of grains, Increases moisture of grains, moisture content due to insects increased fungal growth, contaminate grain with excreta, scales, hair, produce smells in grains, cause allergies which cause eye irritation, miscarriage, dermatitis, catarrh, colic, respiratory problems (Holscher, 2000).

The science behind the use of metal silos

The most important thing in keeping the grains safe from pests and Aflatoxin is low moisture content of grains. However, each type of stored grain has its moisture content requirement before storage. For example, maize needs less than 13.5% moisture content. If farmers do not have moisture meters they can do a "salt test", in which the hygroscopic properties of salt are used to determine the moisture content of grains. The procedure uses a hand full of grains, which is put into a clean dry bottle and two tea spoonful of dry common salt added and mixed. The bottle is closed tightly and kept for 20 minutes. After which the mixture is shaken and if particles of salt are seen sticking on the sides of the bottle, then it is inferred as not dry and hence cannot be put in the metal silos. If the grain is dry and is transferred into the silo, a burning candle is placed on the grains and the silos closed so that the oxygen in the grain is consumed. The nitrogen conditions created coupled with cold temperatures and low water activity keep the pest population in the grains at manageable low levels for a long time. Hence, it is important to keep the Metal silos away from direct sun light and placed on a wooden pallet to keep them cool (Figure 2). All this details are supplied by the metal silo dealers to the farmers.

We hope farmers can urgently adopt this time tested modern technology and use it to supply grains, which is more safer for the consumers and also make agriculture an income generating activity which can tap into the best prices by having the best quality of grains at the most prime time in agribusiness.

Figure 2. The adoption of the small scale metal silo in grain storage instead of the wooden crib (A) can be a great step in reducing post harvest losses of grains in sub-Saharan region. The metal silo usually has one grain inlet (B) which is secured with a rubber band (C) and an outlet (D). The metal silo is usually placed on a wooden pallet (E) to keep it cool.

Aflatoxin mitigation Model for the grain supply Chain

Various studies have suggested that effective reduction of aflatoxin contamination in the food supply would require a multifaceted approach. This must involve several components like pre harvest breeding strategies, biological control, harvest and post harvest management strategies (Figure 3). The pre-harvest host resistance is one of the simultaneous strategies to mitigate aflatoxin contamination in cereals like maize. This is based on the fact that *Aspergillus flavus* infects susceptible maize plants and produces aflatoxins before harvest. There have been several approaches in identifying natural resistance in maize plants although studies have shown that such resistance is polygenic and complex. Strategies to confer *A. flavus* resistance to high yielding stress resistant varieties while limiting the transfer of undesirable traits are still being sought. However, many developing countries can early mitigate the severity of Aflatoxin contamination by continually identifying and utilizing additional sources of corn genotypes with resistance to aflatoxin contamination (Abbas et al., 2009).

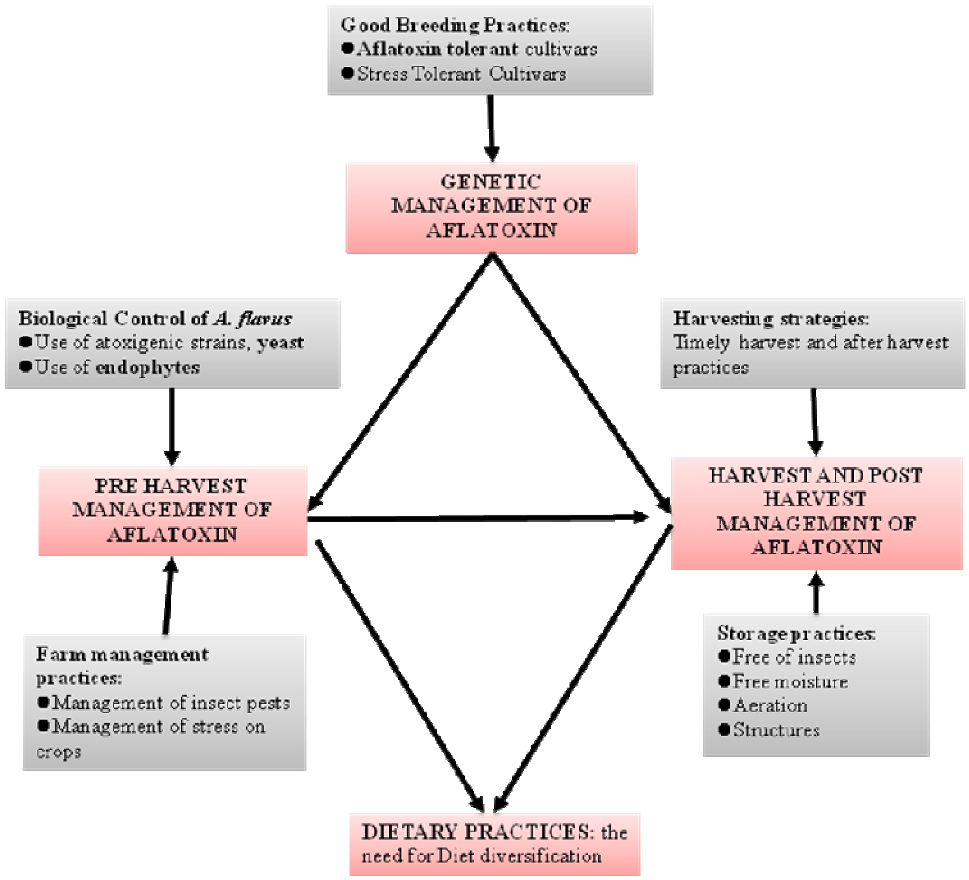

Figure 3. An integrated Aflatoxin mitigation approach model, showing the link between genetic, pre harvest, harvest, post harvest and dietary diversification strategies in the grain supply chain.

The development of the pre-harvest Aflatoxin host-resistance strategy

The development of pre-harvest host plant-resistance is an area of intense study for the control of aflatoxin contamination [Campbell et al., 1997; Bhatnagar et al., 2008; Cleveland et al., 2003). This is because *A. flavus* infects affects crops prior to harvest and a host-resistance strategy may be the easiest for the grower to integrate into the various crop management systems to prevent pre-harvest contamination with aflatoxins (Campbell and White, 1995). It is encouraging that several maize lines have been identified and developed with increased resistance to *A. flavus* infection and aflatoxin contamination and this has enabled the identification of natural resistance traits (Brown et al., 2004; Brown et al., 2006), although such findings have been controversial.

In many countries in Africa the major breeding criterion has been maize productivity per hectare, however, there are other equally important attributes such as pest and disease resistance, drought, fast dry out after physiological maturity, husk cover to reduce cob rot, flintiness (hardness) to increase poundability of the grain etc. Some of these characteristics are important in mitigating aflatoxin susceptibility and should be considered by seed developing and bulking companies. Considering that aflatoxin outbreaks have occurred in the country since 1960 with the highest epidemic levels in 2004 in Kenya. Furthermore, it is very likely that farmers will be willing to pay for new strains that are resistant to aflatoxin contamination, given the success which Seed Companies had with selling seed varieties resistant to maize streak virus and Striga.

On farm Aflatoxin contamination of grains and its entry to the food chain

The global Center for Disease Control has estimated that more than 4.5 billion people in developing countries are chronically exposed to aflatoxins in their diets. Cereals especially, maize grains, can be prone to aflatoxin contamination, particularly when they come into contact with infested soil during harvesting, threshing, and drying. Contamination can also occur when grains are in storage due to pest infestation and the poor conditions that lead to accelerated growth rates of *Aspergillus* fungi and aflatoxin production. Although Aflatoxin is produced in minute quantities, its potency, prevalence, and the ease with which it can permeate farmers' fields and storage areas make this highly carcinogenic metabolite particularly dangerous (Wu, 2004). However many farmers and consumers are not aware that one cannot see, smell, feel, or taste aflatoxin in grains and that laboratory testing is required to discover its presence. You can, however, avoid the use of grains suspected to be contaminated. Some consumers assume that boiling of maize can destroy aflatoxin, but this is not the case as normal boiling cannot destroy Aflatoxin. Others think that grinding contaminated grain can make it less dangerous and a large group of farmers also think that moldy cereals like maize can be fed to poultry, but chicken are even more susceptible to aflatoxin contamination and can furthermore be accumulated in the eggs which are consequently eaten by human. Some studies have shown that Aflatoxin poisoning is accumulative in the human body. Acute exposure to high levels of aflatoxins leads to aflatoxicosis, which can result in rapid death from liver failure (Amaike and Keller, 2011). In 2004, during the worst known outbreak of aflatoxicosis in Kenya, 317 cases were reported and 125 people died. The minimum level of aflatoxin exposure required to cause aflatoxicosis is not known, but the disease mostly affects children. Unfortunately, developing countries in many regions of the world, such as Sub-Saharan Africa, cannot afford the costs associated with the monitoring and mitigation of aflatoxin in food and feed crops. This has led to an increased risk of exposure to aflatoxin resulting in outbreaks of acute aflatoxin poisoning (aflatoxicosis) (Ngindu *et al*., 1982; Probst *et al*., 2009).

Exogenous biological control strategies of Aflatoxin in maize

The fungus, *Aspergillus flavus* produces aflatoxin which is the most potent carcinogen known. It is very hazardous to the health of both human and animals. Regional economic losses are in the billions of dollars per year due to aflatoxin contamination of agricultural commodities; currently (2012), Kenya has 160,000 contaminated bags of maize (personal communication with Agriculture dept. 2012). Aflatoxin levels of 2-4 ppb have been declared mandatory by importing European Countries (Commission of the European Community, 1998). However, even very low levels of infection of the nuts, corn, peanuts and cotton seeds by *A. flavus* can

result in aflatoxin levels above these mandatory standards. Managing pre-harvest aflatoxin contamination via biological control, is a promising and environmentally-friendly approach. The current use of exogenous atoxigenic *Aspergillus flavus* is under trial in several Sub-Saharan countries including the pioneer countries of Nigeria and Kenya, The preliminary results from these trials are very promising. Aflatoxin contamination is well documented to be associated with wounding in corn, peanuts, cotton seeds and tree-nuts before harvest. A bioassay has been developed to screen for effective yeast inhibiting both the growth of the *Aspergillus flavus* and aflatoxin production (Hua et al., 1999).

Endogenous biological control of Aflatoxin in maize

Hybrid maize production has increased world maize production, nevertheless, no maize hybrid has been found to be free from mycotoxin contamination especially aflatoxin or fumonisin. The use of biological control with microorganisms, including fungi and bacteria, against plant pests and diseases has been found to be effective. However, studies have shown that there are microorganisms that are naturally associated with crops and have been found to offer protection to crops from insect pests and diseases (Arnold, 2007). However, the indiscriminative use of pesticides can destroy these beneficial associations between plants and microorganisms. These protective microbes, which are called endophytes, grow together with crops without the production of symptoms and have no negative effect on their hosts (Bayman, 2007). It has been shown that diseases of fungal, bacterial, viral origin and even damage caused by insects and nematodes have drastically been reduced after a prior inoculation with endophytes (Figure 4). Therefore, unique endophytes could be used directly to treat seeds or transplants limiting substantially the side-effects of abiotic and biotic factors. Endophytes have been found to reduce the effect of seed mycotoxin contamination and research on them could be of great importance to agri-food industries (Faeth and Fagan, 2002). This approach of pest management should be attractive to the biotechnology industry looking for alternatives to traditional pesticides, since targeting the pathozone of pathogen and insect infestations assures improved efficacy. Indeed, the future use of endophytes in combination with fewer pesticides applied to the seed or seedling could lead to synergized effects on one or multiple insect pests and disease causing agents. As a result, there is a considerable potential to find new and beneficial endophytic relationships in different ecosystems especially in major crop plants.

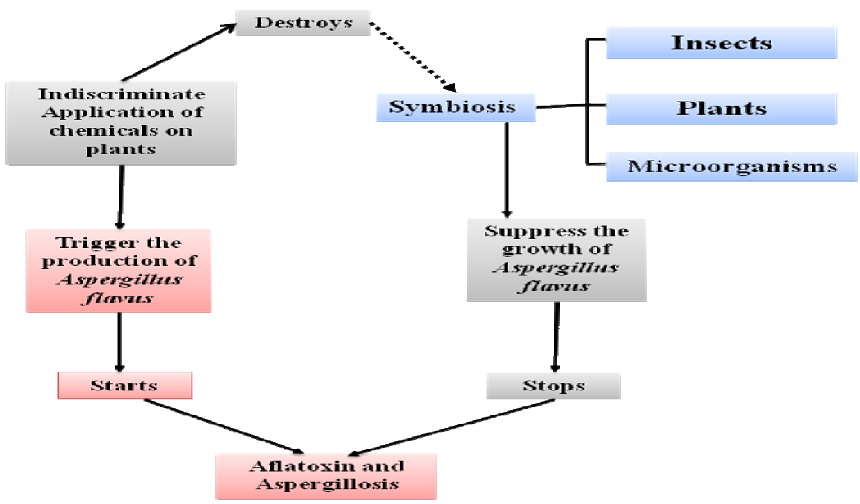

Figure 4. A model showing the relationship between the indiscriminate application of chemicals, natural symbiosis in plants and possible outbreaks of *Aspergillus flavus* aflatoxin poisoning and Aspergillosis.

Conclusion

The post harvest period is that part in the food life cycle which covers all stages after harvest and includes cleaning, grading, transportation, storage, processing and packaging and marketing. In terms of economics, it is the period when the highest value is added to the grain product before it gets to the consumer. If any grain is not handled in a way that maintains its quality, that product can lose its value and hence affect the livelihoods of all those involved in the supply chain. Moreover, the post-harvest losses are also supposed to be inclusive of the inputs, such as land, labour, fertilizer, water which are all scarce resources involved in agricultural production. Effective postharvest management can contribute to conservation of scarce resources while minimizing the need to produce more food to cover the losses caused by lack of appropriate postharvest technologies and strategies. By the year 2025 it is estimated that the global food output must increase by about 75% to feed a population estimated to be close to 9 billion. Hence by then we shall need 2.8 billion tonnes of cereals, 5.3 billion tonnes of other crops, 1.6 billion tonnes of animal products. Hence, it is currently important to consider post-harvest grain management as strategic policy concern especially in the Sub-Saharan region where there is a dramatic increase in population growth and reducing agricultural land.

Post-harvest management is a crucial component of food production in developed countries. However, it is still neglected in the developing countries where large losses from farm to plate have been attributed to poor handling, distribution, storage, and purchase/consumption behavior. Although the main investment in addressing global hunger has been on increasing food production, it needs to be complemented with comprehensive programs which address the huge postharvest losses especially in the famine prone Sub-Saharan countries. Recent studies have shown that this is surely one of the most sustainable alternatives to increasing food security. The highlight of this review, which links food security, farm management, Aflatoxin mitigation, agribusiness and crop diversification to post-harvest management justifies an investment in reducing post harvest losses in any country.

Acknowledgement

We would like to thank the Australian Government through AusAID for sponsoring the Australian Awards in Africa Short course on Post harvest management of maize, legumes and rice in South Africa, Australia and Ghana where the concepts and models in this paper were crystallized. We also acknowledge the inputs of Dr. Harriet Muyinza (Uganda), Francis Musavi (Kenya), Martha Masango (Malawi). Martin Nduwimana (Burundi), Blanche Iya Etongwe (Cameroon), Sylvestre Boudzoumou (Congo), Tsegereda Nigatu (Ethiopia), Christelle Awa Ndong (Gabon), and Biraguitcha Anwone (Togo)

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Cite this Article: Josphert N. Kimatu, Robyn McConchie, Xiuyuan Xie, and Simon N. Nguluu (2012). The Significant Role of Post-Harvest Management in Farm Management, Aflatoxin Mitigation and Food Security in Sub-Saharan Africa**.** Greener Journal of Agricultural Sciences, 2(6): 279-288, http://doi.org/10.15580/GJAS.2012.6.10021269**.**